An Experimental Study of Footprint Scale Variability of Raindrop Size Distribution

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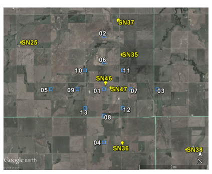
1. Introduction

Non-Unform Beam Filling (NUBF) within footprint of the dual frequency precipitation radar (DPR) on board NASA's Global Precipitation Measurement (GPM) mission core satellite is one of the key uncertainties of the precipitation retrieval algorithms. NUBF is a combined effect of precipitation gradient and intermittence within the footprint and occurs due to spatial variability in both horizontal and vertical direction. While the scanning and vertically pointing radars are the solo source to study the spatial variability in vertical, the dense rain gauge and disdrometer networks are often employed to determine the spatial variability in horizontal direction. The disdrometer networks are mainly available through field campaigns and in a few ground validation sites but are superior to the gauge network due to their higher temporal resolution and ability to measure raindrop size distribution and related integral rain parameters. This study uses disdrometer network that was operated during from Mid-latitude Continental Convective Clouds (MC3E) campaign to study the spatial variability within the footprint of DPR.

2. Field Campaign

The MC3E campaign, a joint effort by the US Department of Energy's Atmospheric Radiation Measurement (ARM) and the NASA GPM GV programs, was conducted in North Central Oklahoma (36.7N, 97.1W) from April 22 to June 6, 2011. Seven (five GPMGV and two ARM) third-generation compact two-dimensional video disdrometers (2DVD) were deployed at and around the ARM Southern Great Plains site where the distances ranged from 0.4 to 9.2 km. For the purpose of this study, it would have been desirable to have uniformly distributed units within a circular area with a diameter of 5 km, representing the DPR footprint. This was not feasible due to power and open space requirements of the site selection. However, the layout and number of units allowed interpolating the 2DVD measurements tot desired points. Figure 1 shows the locations and interpolation points of the 2DVDs. The locations are given based on serial number (SN), while the interpolated points are numbered from 01 to 13. Table 1 presents the coordinates and distances between the points.



	01	02	03	04	05	06	07	08	09	10	11	12	13
	36.605° 97.489°	36.628° 97.489°	36.605° 97.479°	36.582° 97.489°	36.605° 97.517°	36.617° 97.489°	36.605° 97.475°	36.594° 97.489°	36.605° 97.474°	36.613° 97.498°	36.613° 97.479°	36.597° 97.478°	36.597° 97.498°
01		2.50	2.50	2.50	2.50	1.26	1.25	1.25	1.25	1.25	1.25	1.25	1.25
02			3.54	5.00	3.54	1.24	2.80	3.75	2.80	1.84	1.84	3.50	3.50
03				3.54	5.00	2.80	1.25	2.79	3.75	3.50	1.84	1.84	3.50
04					3.54	3.76	2.80	3.75	2.80	3.50	3.50	1.84	1.84
05						2.80	3.75	2.79	1.25	1.84	3.50	3.50	1.84
06							1.77	2.51	1.77	0.96	0.96	2.32	2.32
07								1.77	2.50	2.31	0.96	0.96	2.31
08									1.77	2.31	2.31	0.96	0.96
09										0.96	2.31	2.31	0.96
10											1.77	2.50	1.66
11												1.77	2.50
12													1.77

3. Data Analysis

The standard processing by GPMGV defines rainy minutes as having a minimum rain rate of 0.01 mm h^{-1} and a minimum number of drops of 10 sampled in one-minute observations. This resulted in an MC3E database of 740 one-minute samples, which were the input for the interpolation routine. Rain intermittence is frequently observed in light stratiform rain and plays an important role in NUBF. We addressed this matter by setting DSD derived rain rates less than 0.1 mm h^{-1} as zero after interpolation. This eliminated 5 samples where the rain rate fell below the threshold in all 13 sites. Surprisingly, only 34 samples had zero rainfall at one or more sites for the remaining dataset. Since the DPR footprint is a single data point from GPM perspective, the areal average rainfall is considered to determine the rainy footprint. Hence, a rain rate threshold of 0.1 mm h^{-1} was applied to the areal average rainfall and 12 more samples were eliminated retaining 723 samples. At least 4 out of 13 sites had zero rainfall in these 12 samples even though one sample had 5 zero rainfall sites but areal average rainfall was above the threshold. Post GPM launch, DPR minimum detectable signals are currently establised at 13 dBZ for the Ka-band high sensitive swath (HS) and for Ku-band normal swath (NS) and 18 dBZ for the matched Ka- and Ku-band swath (MS). The corresponding sample sizes were 703 and 698 for HS and NS, respectively, and were 639 for MS.

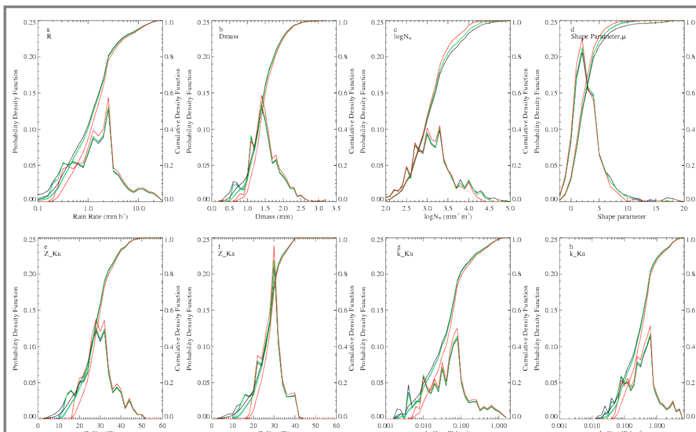
4. Methodology

A three-parameter exponential function is adopted to investigate the spatial variability of DSD and integral rain parameters. The exponential function is expressed as:

$$r(d) = r_0 \exp\left(-\frac{d}{d_0}\right)^{S_0}$$

where r_0, s_0 are nugget and shape parameters, respectively, and d_0 is the correlation distance. The Pearson correlation coefficient, r, is calculated between the paired 2DVD observations at distance, d. The r_0 is the correlation between the collocated observations and is set to 0.99 in the absence of collocated 2DVDs. It should be noted that there is variability in drop counts at spatial scales 1-100 m but the correlations of derived DSD and integral rain parameters are mainly higher than 0.90. An initial guess was made for d_0 and s_0 using ranges of 0 to 300 at an increment of 0.1 and 0 to 2 at an increment of 0.01, respectively. The d_0 and s_0 are calculated minimizing the root-mean square error (RMSE) between the observation and equation based correlations. The RMSE is the measure of the goodness of the fit and it is critical for the interpretation of d_0 and s_0.

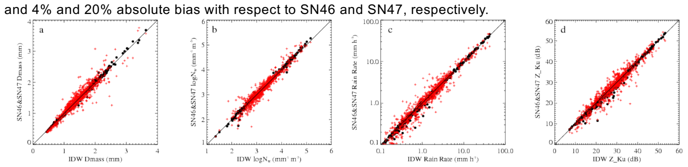
5. Probability and Cumulative Distributions



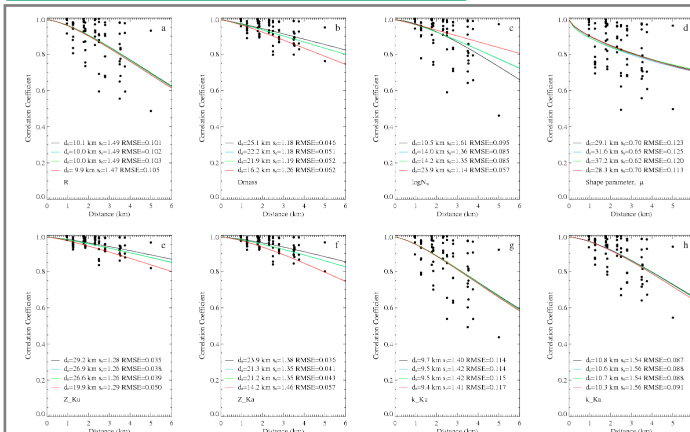
Moderate-to-heavy rain in southern Great Plains receives relatively high percent of contribution from large drops (> 3 mm in diameter). The presence of large drops results in 14% of the observations $D_{mass} \geq 2.0$ mm at MS threshold. For the same threshold, 11% and 16% of the observations had Z_Ku ≥ 40 dBZ and k_Ka ≥ 1 dB km^{-1}, respectively. The presence of large drop results also in broader size distribution with relatively low shape parameter of the modeled gamma distribution. The MC3E dataset exhibited drastically different properties than a preceding study conducted at the mid-Atlantic coastal site of Wallops Island, Virginia where virtually no observations of R ≥ 10 mm h^{-1}, $D_{mass} \geq 2.0$ mm, and Z_Ku ≥ 40 dBZ occurred.

6. Inverse Distance Weight

The accuracy of the Inverse Distance Weight (IDW) is tested through cross comparison of four physical parameters, D_{mass}, $\log N_W$, R, and Z_Ku, between SN46 and site #01 and between SN47 and site #01. Site #01 is 0.15 and 0.34 km from SN46 and SN47, respectively. There were 707 samples where SN46 and SN47 measured R ≥ 0.1 mm h^{-1}. Figure 2 reveals an excellent agreement between the observed and interpolated parameters. There was also no systematic over- or under-estimation of any parameter. Site #01 had a better agreement with SN46 due to its closer distance. Rain rate was slightly overestimated with 0.6% and 1.8% bias and 4% and 20% absolute bias with respect to SN46 and SN47, respectively.

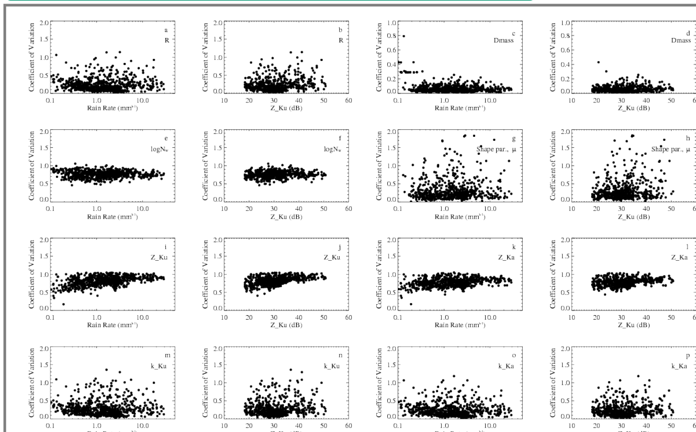


7. Spatial Variability: Correlation Coefficient



The correlations at a given distance were not sensitive to the choice of threshold for R, k_Ku and k_Ka fields. The parameters of exponential function were therefore very close to each other for all four thresholds. At the same time, there were substantial differences in correlations at a given distance. The correlation of R ranged from 0.93 to 0.48 at 5 km distance for a given R threshold. This resulted in high RMSE for these three fields. The correlations of μ were not sensitive to the choice of threshold but highly sensitive to the directional variability. The RMSE of the fit was therefore the greatest for μ among all fields. The s_0 was lower than 1.0 only for this field and corresponding d_0 was high even though the correlations were less than 0.8 for nearly half of the observations. The correlations at a given distance were more sensitive to the choice of threshold for Z_Ku, Z_Ka, and D_{mass} fields where correlations remained above 0.75 regardless of distance in R threshold database. The correlations of $\log N_W$ also showed sensitivity to the choice of threshold but in reverse order. The exponential fits were then lowest and highest RMSE at MS and R thresholds, respectively.

8. Spatial Variability: Coefficient of Variation



Coefficient of Variation (CV) represents the degree of uniformity of the parameter from highly uniform (CV ≤ 0.25) to extremely variable (CV > 1.00) classes. The remaining three classes may be called mostly uniform (0.25 < CV ≤ 0.5), mostly (or moderately) variable (0.5 < CV ≤ 0.75), and highly variable (0.75 < CV ≤ 1.0). All physical parameters had CV ≤ 1.25 except the shape parameter of gamma model distribution. The vast majority of R had CV ≤ 0.5, only 8% of the observations showed moderate to extreme variability (CV > 0.5). D_{mass} was highly uniform across the range of R and Z_Ku values and had two outliers with CV of 0.7 and 0.8. These outliers occurred in back-to-back minutes during a deep convective event where one and two sites did not report rainfall. The vast majority of the observations fell into moderate to high variability classes for CV of $\log N_W$. The shape parameter, on the other hand, had over a dozen samples where CV > 2 was (not shown). These samples correspond to DSD where gamma distribution is probably not the best choice. The CV of Z_Ku exhibited mostly high variability but significant number of samples had also moderate variability. The CV of k_Ku fell mostly into the highly uniform class and the majority of the database had CV < 0.5.

Acknowledgments

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